TNO innovation for life

Fiber based hydrophones for ultra-high energy neutrino detection

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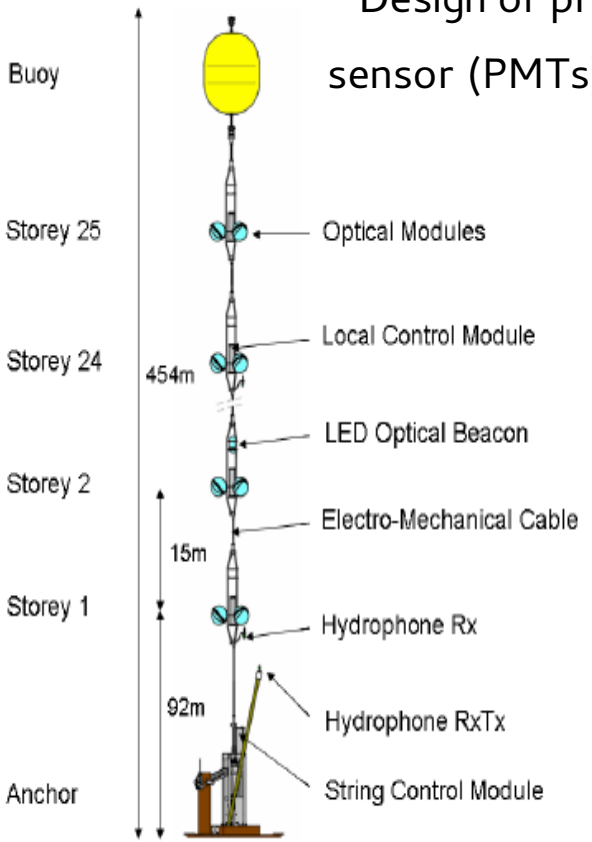
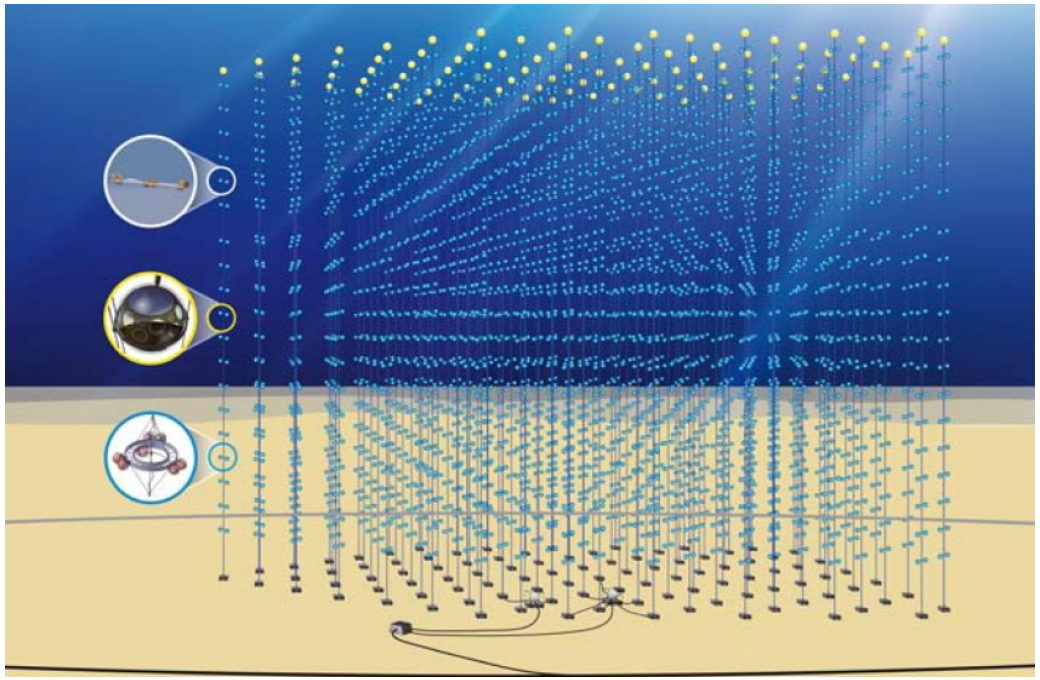
Cosmic-ray experiments in water and ice

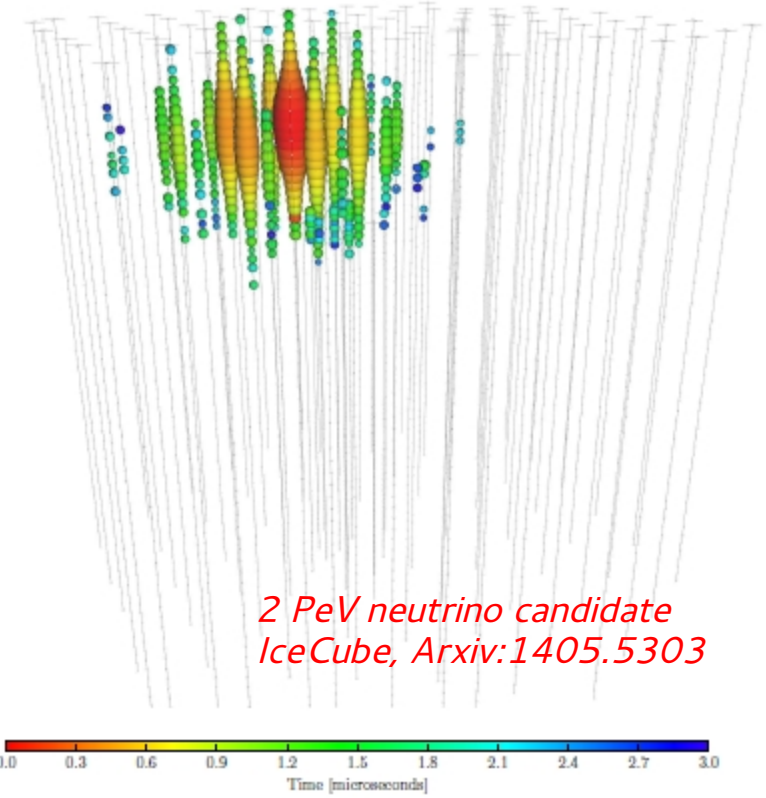
- Detection and study of high energetic cosmic neutrinos.
- Use water or ice as a detection medium
- Design of present experiments is based on strings equiped with light sensitive sensor (PMTs) to detect Cherenkov radiation from particle showers.





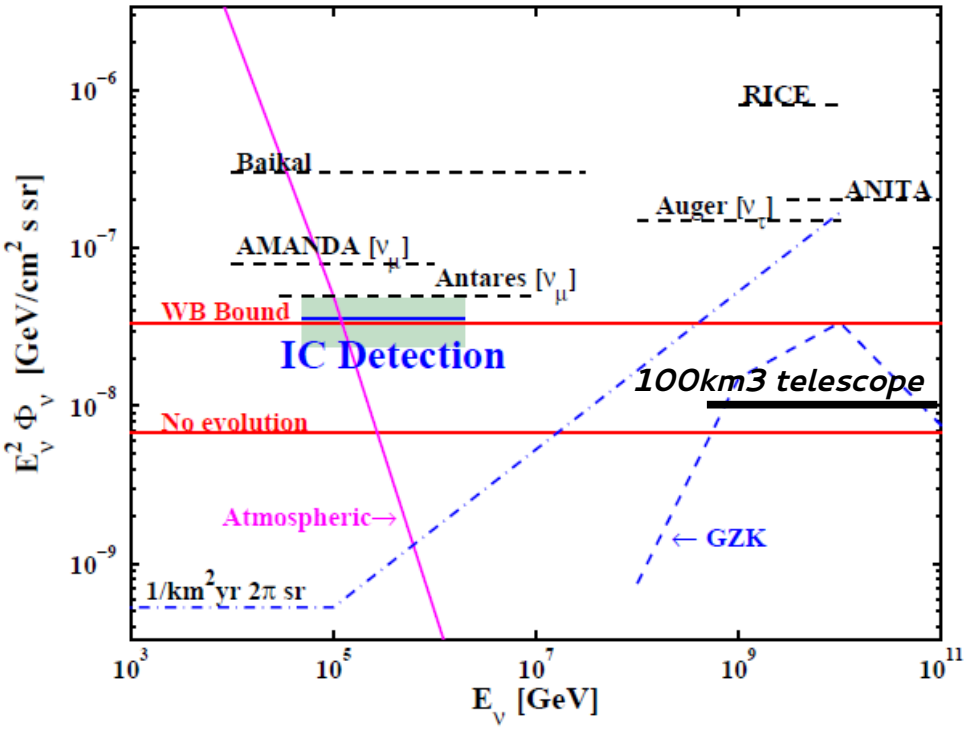
Cosmic ray neutrinos: energy range

- Present neutrino telescopes (IceCube, KM3NeT) are designed to detect energies up 10^{15}– 10^{16} eV:
  - 37 candidates between 60 TeV and 3 PeV detected by IceCube



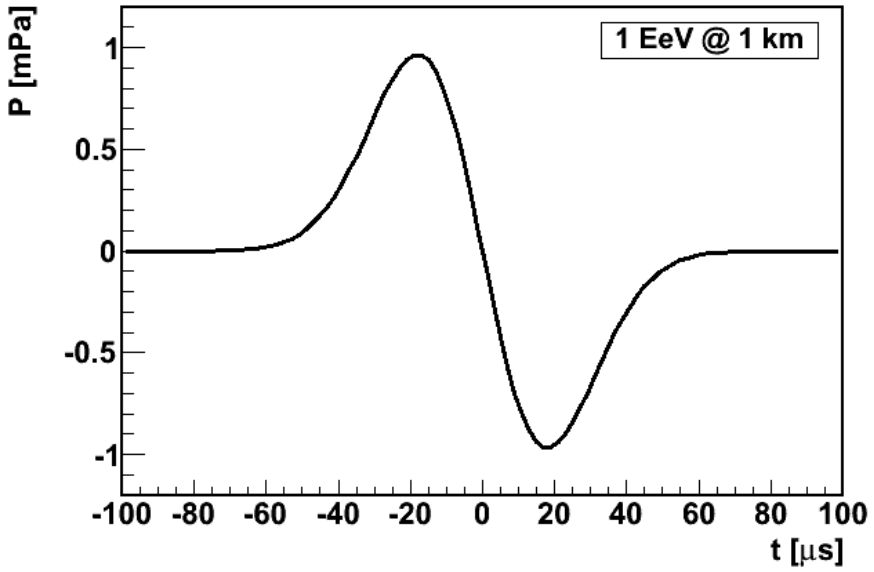
2 PeV neutrino candidate
IceCube, Arxiv:1405.5303

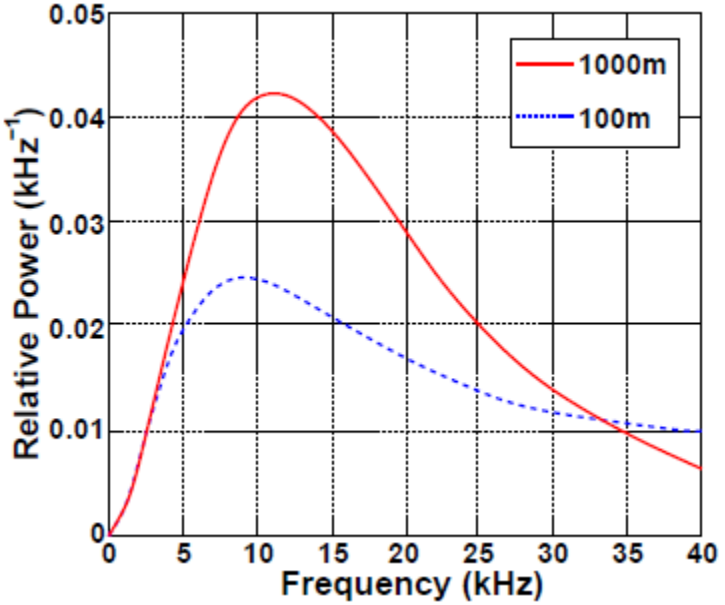
Waxman, Arxiv:1312.0558



Acoustic particle detection

- Principle of acoutic detection: pressure pulse.
- First measurements using accelerators in the 60's (Askarayan, Learned, Sulak).
- Recent work done at UCL, Erlangen, Rome, ITEP and others:
  - Measurements at particle accelerators, hydrophone development
  - Simulation of hadronic showers and generation of acoustic signal

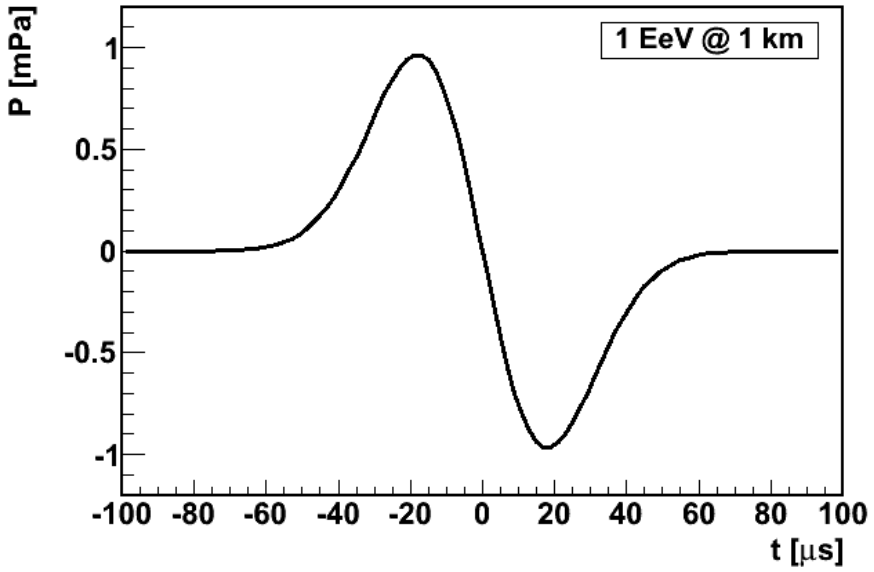


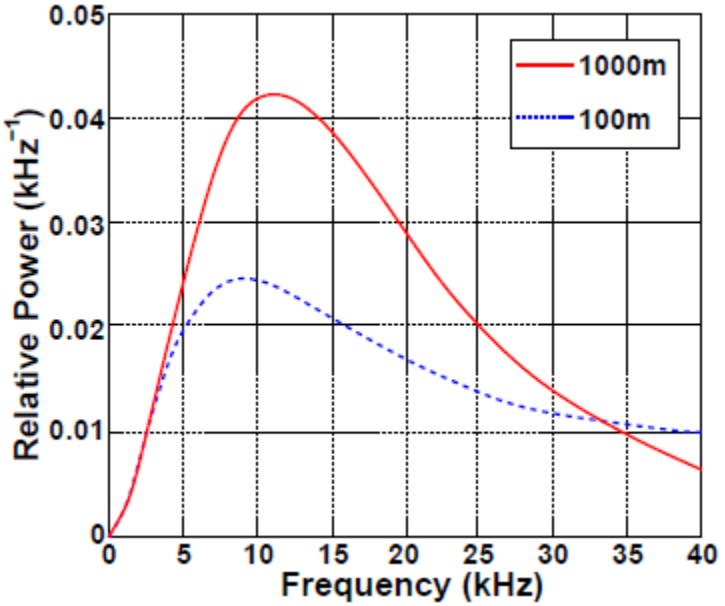


K. Graf, Erlangen, 2008

Expected acoustic signal

- Maximum of the signal between around 10 kHz, signal extends up to 30 kHz.
- Omni-present noise is represented by the Knudsen formula. It defines the background as so-called deep sea states.
- Large experimental set ups could be achieved using acoustic detection, because of the less absorption of sound in water (~1 km @25 kHz).





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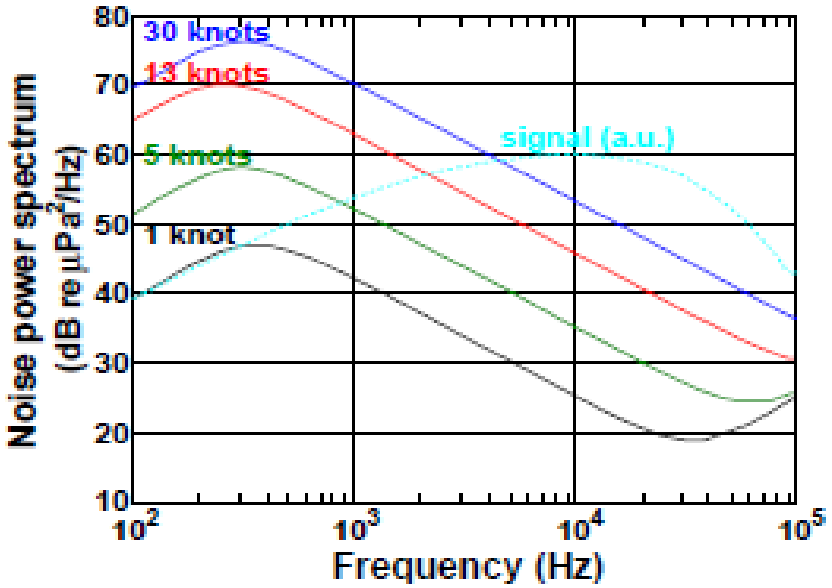
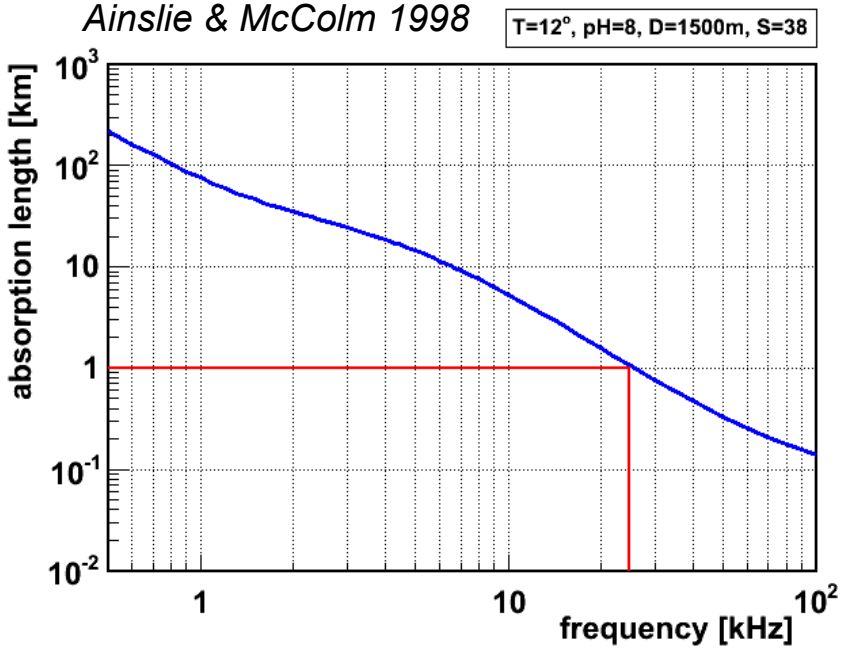


Ainslie & McColm 1998



Requirements on hydrophone system

- Sensitive:
  - Detect pulses at the **mPa** level in the frequency range **5–30 kHz**
  - Sensitive to deep sea state zero
- Simple, robust and simple to integrate
- Price < 100 euro/sensor: >1000 sensors are required to build a large network.

Fiber hydrophones system

- Main components:
  1. Fibers with an Erbium doped grating
  2. Sensor
  3. Interogator

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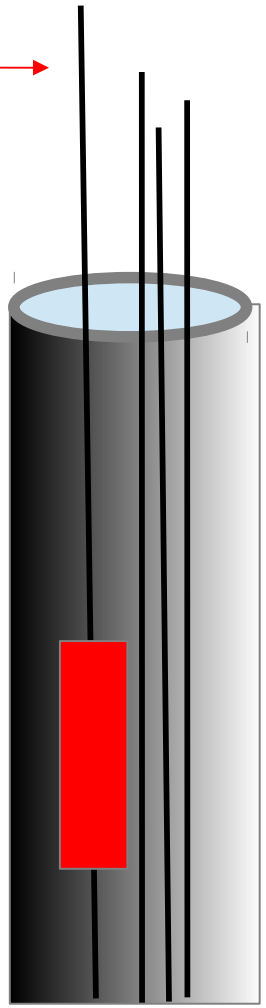
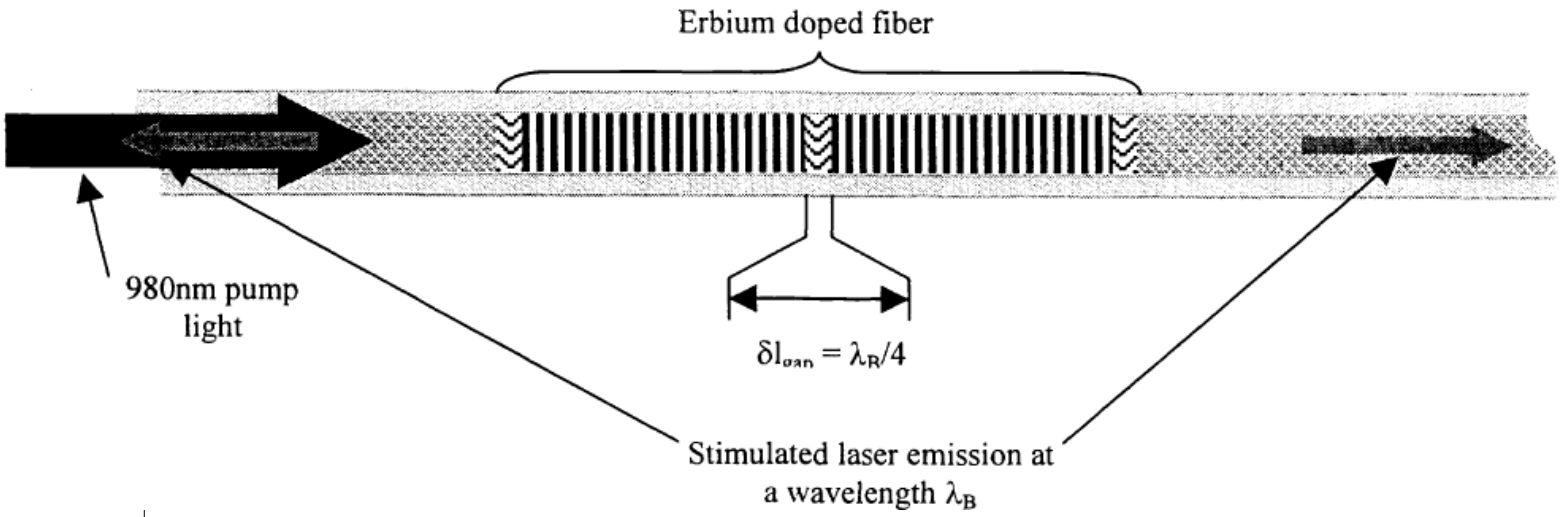


oil filled hose

1. Erbium doped fibers

- Pump laser λ=980 nm, Erbium induced emission light λ=~1550 nm.
- Erbium is implemented in a grating structure. This results in an extremely coherent light source in the fiber it self.
- Include multiple sensors with an specific grating for each sensor.
- Up to ~10 - 20 sensors/fiber.



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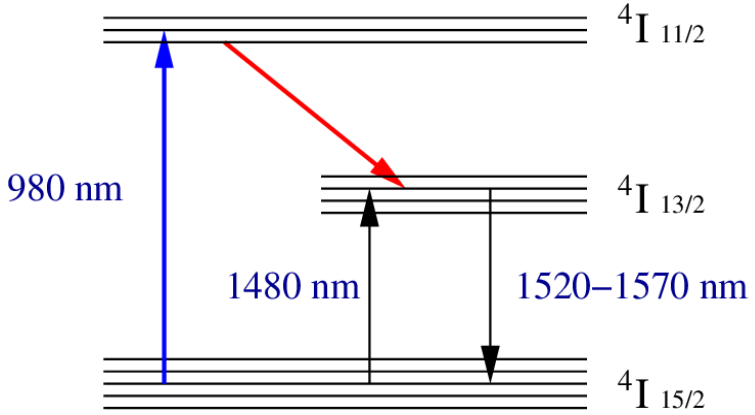
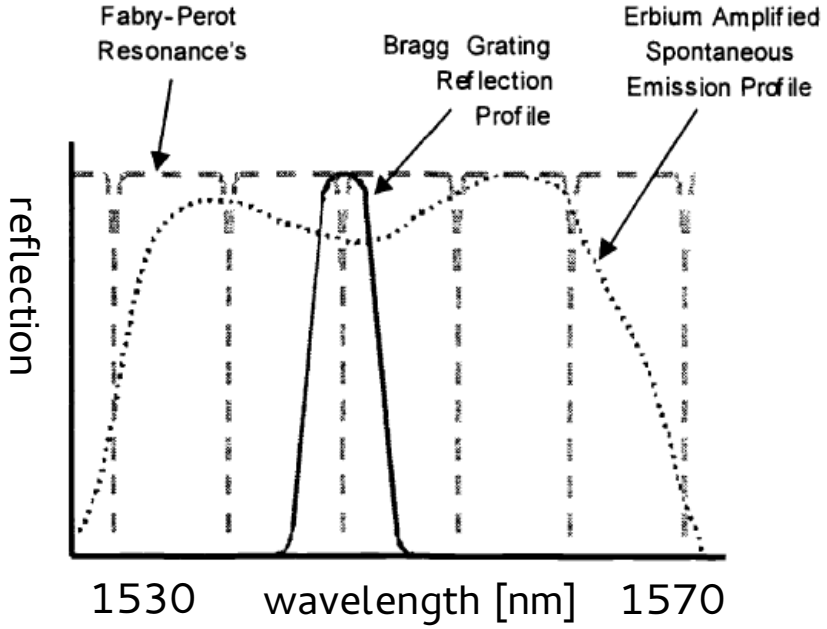
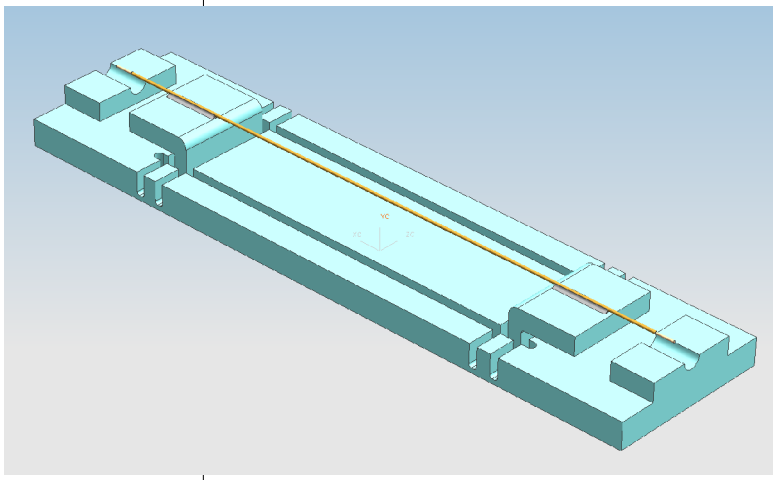




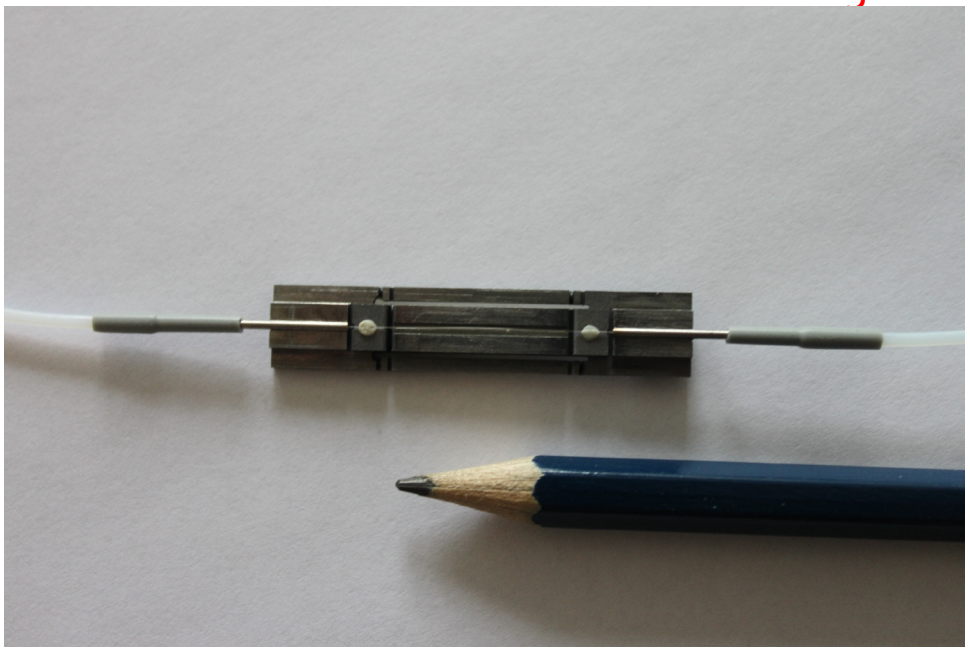
2. Sensor

- Convert presure pulse to a mechanical deformation of the fiber: strain
- Mechanical sensor determines the dynamical frequency range.



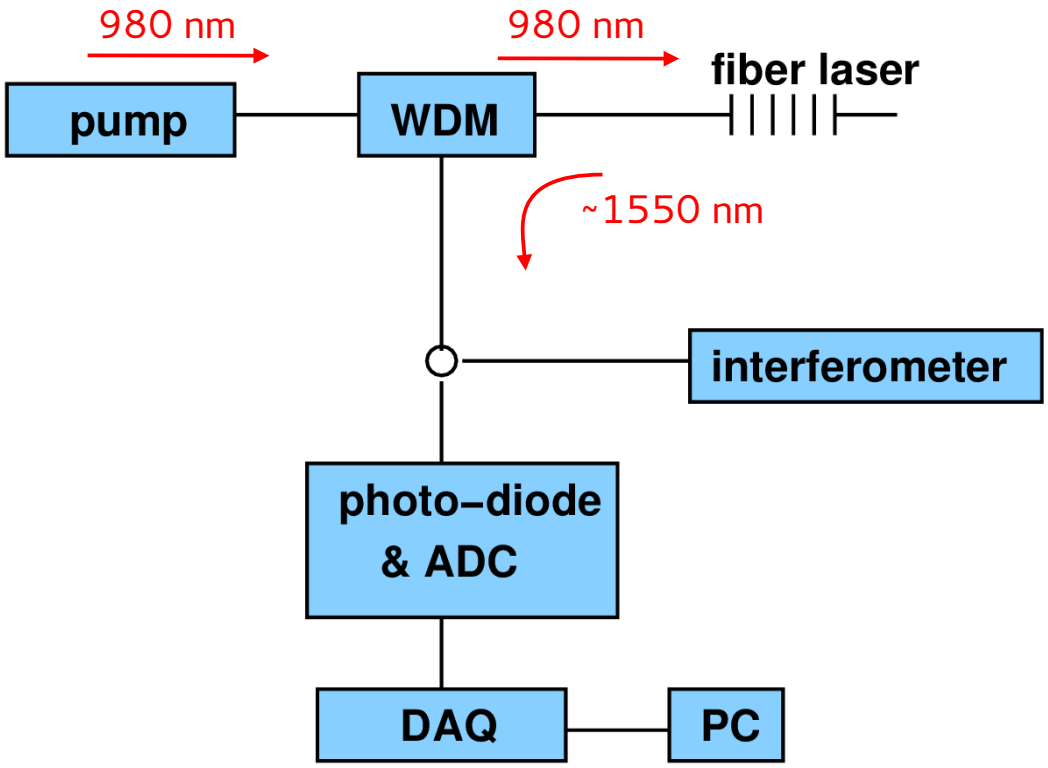
CAD model
Dimensions: 45x9 mm

Sensor with fiber glued



3. Interogation system

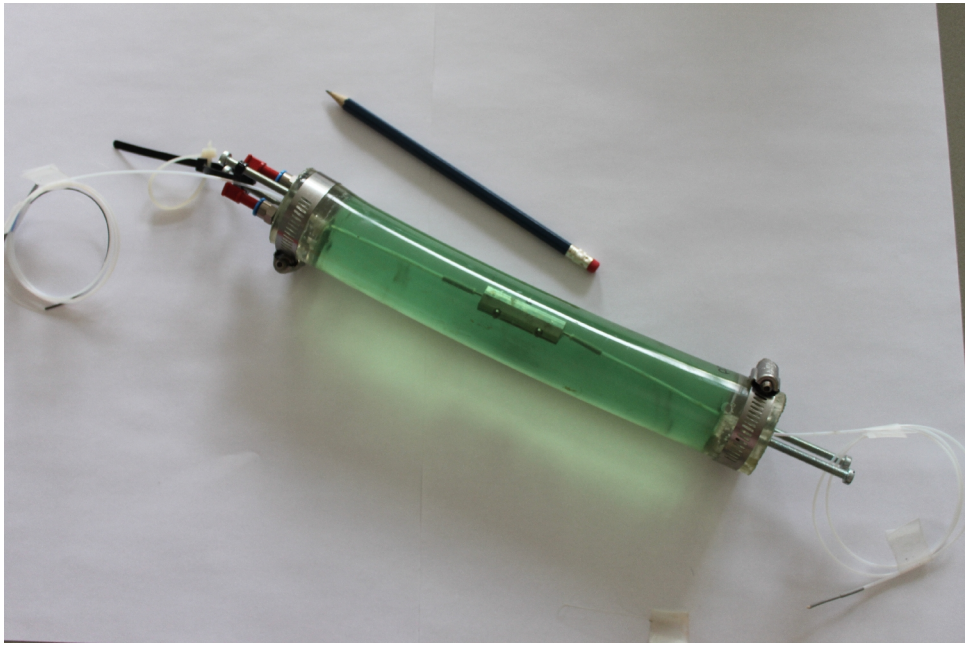
- A fiber is used to read out an interogator.
- Pump laser power ~100 mW
- Received power ~10 µW



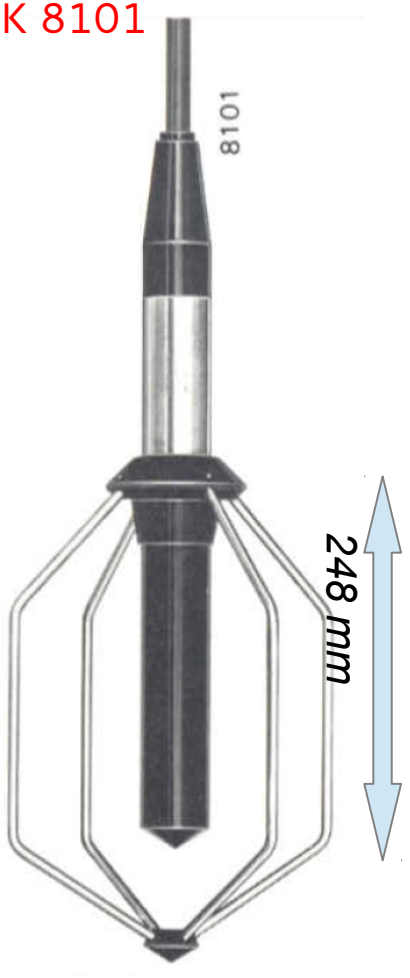
Hydrophone characterization

- Sensitivity, noise measurements.
- Linearity.
- Measurements in an oil filled hose.

Oil hose

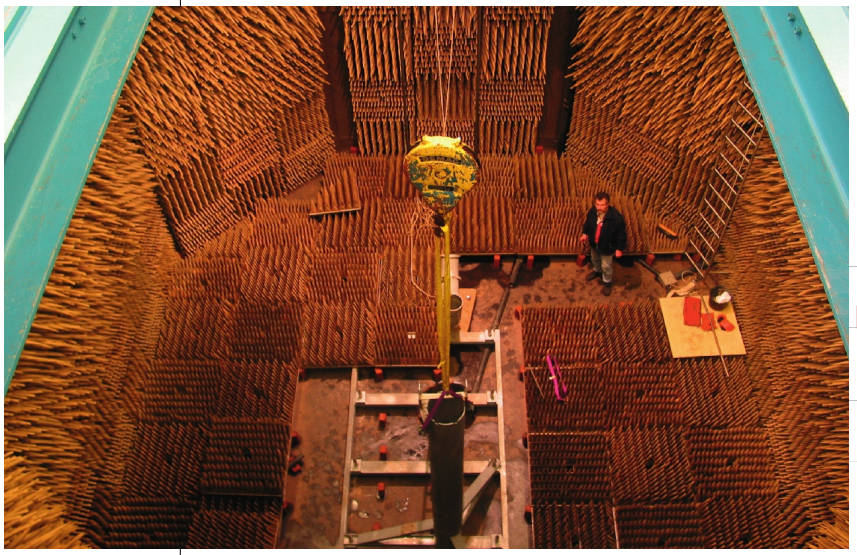


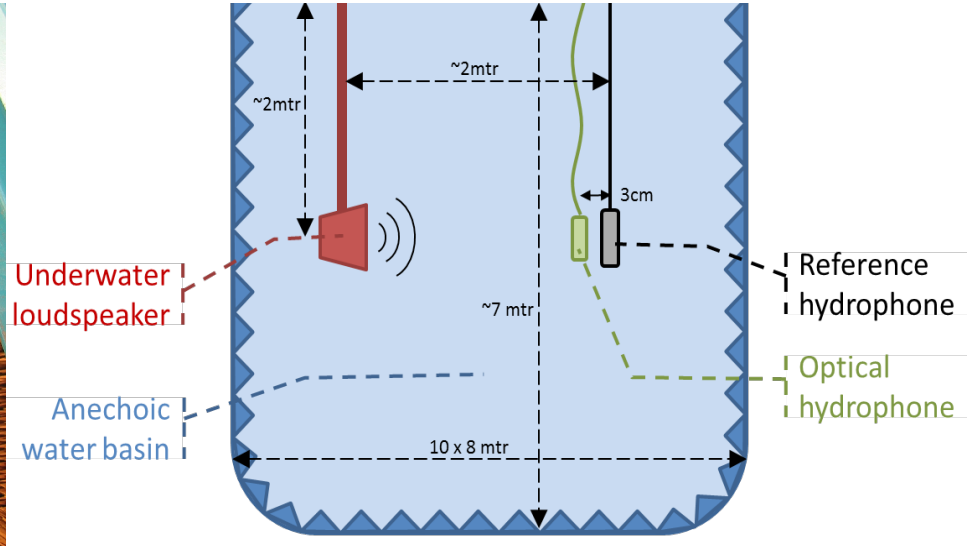
Reference hydrophone
B&K 8101



Experimental setup in basin

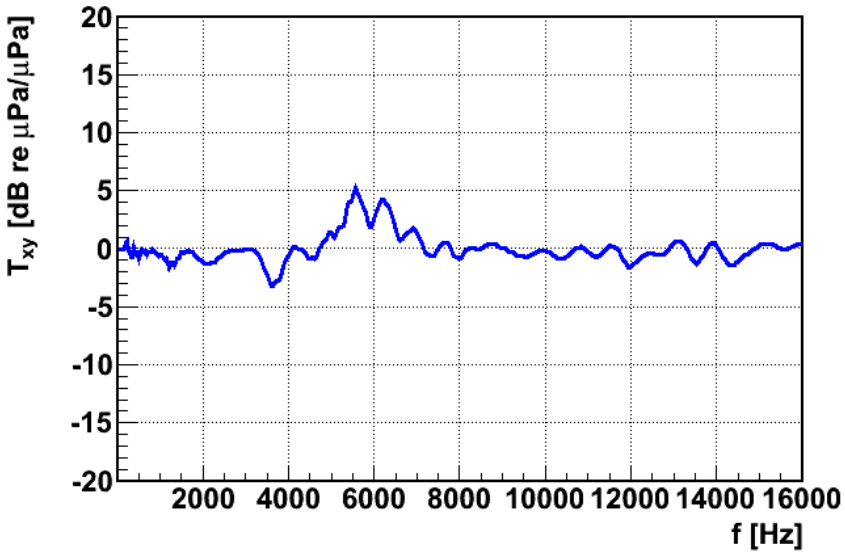
- Using an anechoic basin at TNO (Acoustically insulated).
- Dimensions of the basin 8x10x7m, (basin should be large to avoid mix of signal and echo).
- Compare to well-calibrated commercial hydrophone





Response function

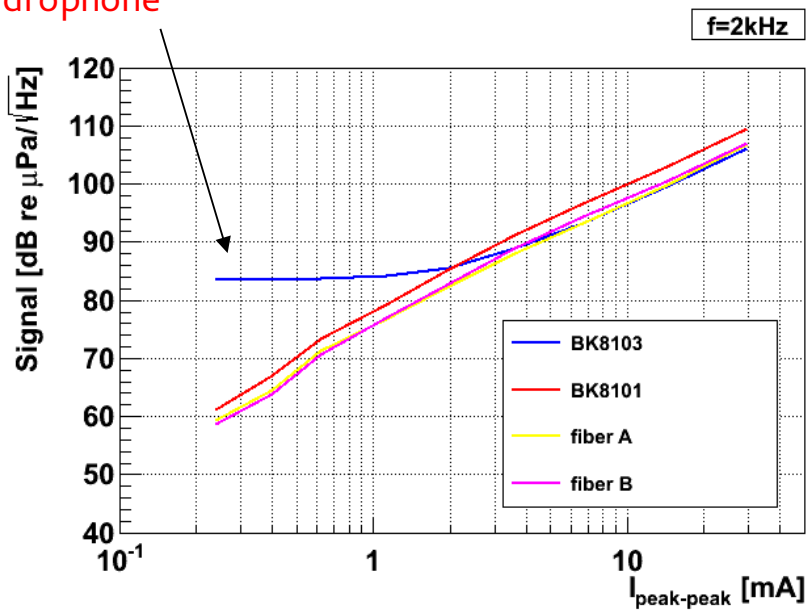
- Response function with respect to the (calibrated) reference hydrophone (B&K8101).
- Response curve is flat. Peak at 5.5 kHz is mechanical resonance.

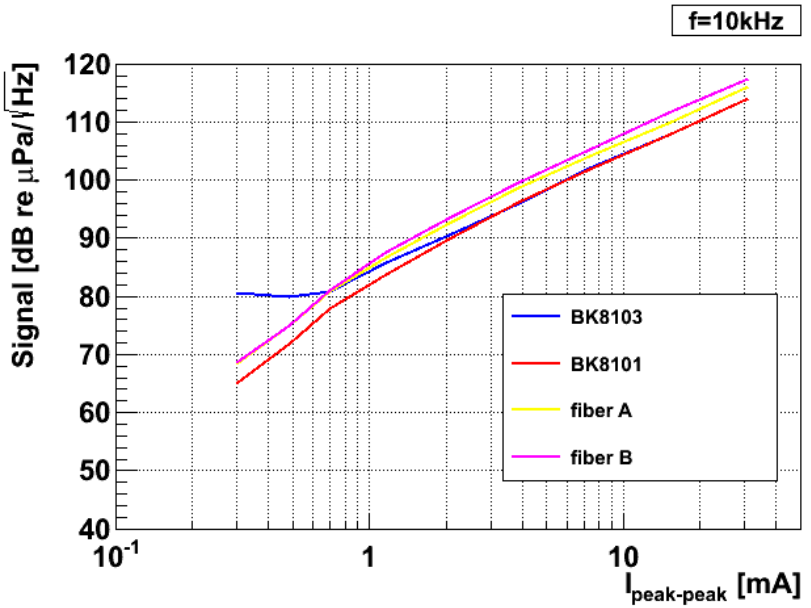


Linearity

- Response to a single tone (at given frequency) is measured as a function of the input current in to the projector.
- Output signal is measured for two reference hydrophones and 2 fiber laser hydrophones.
- Fiber laser hydrophones are linear down to levels compared to sea state 1

Noise in B&K hydrophone



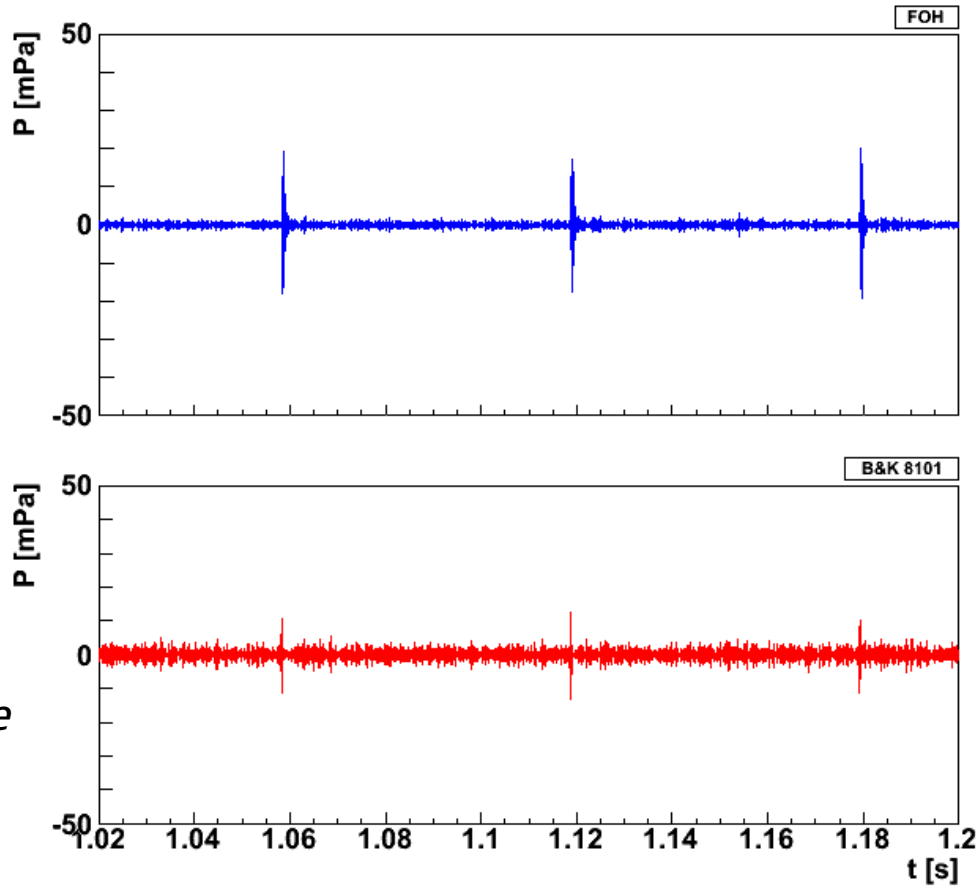


Pulse reconstruction

- Pulse train was generated to detect individual pulses
- Simple passband filter was applied (4th order Butterwordth)

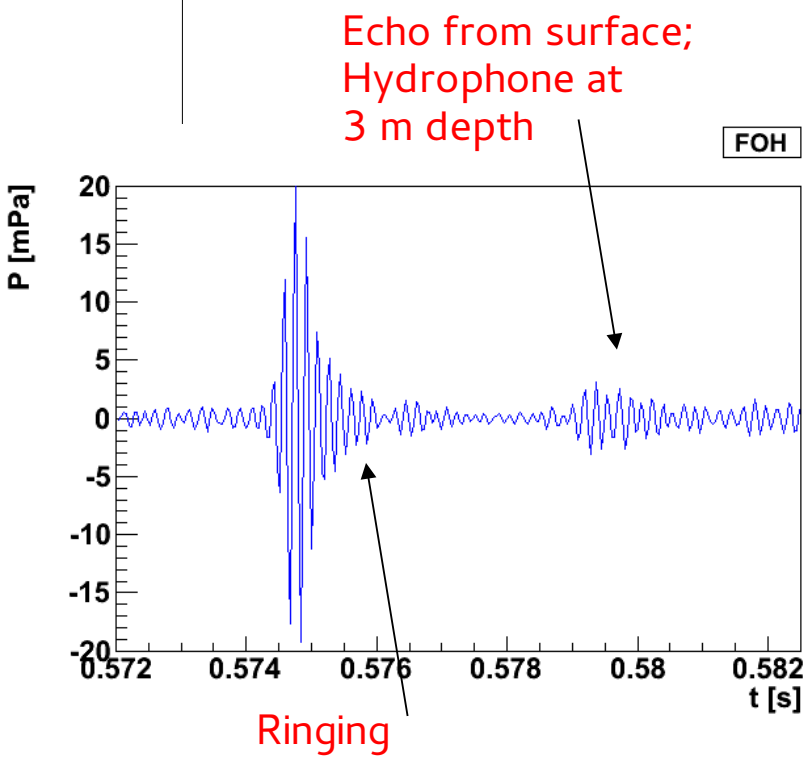
Fiber laser hydrophone

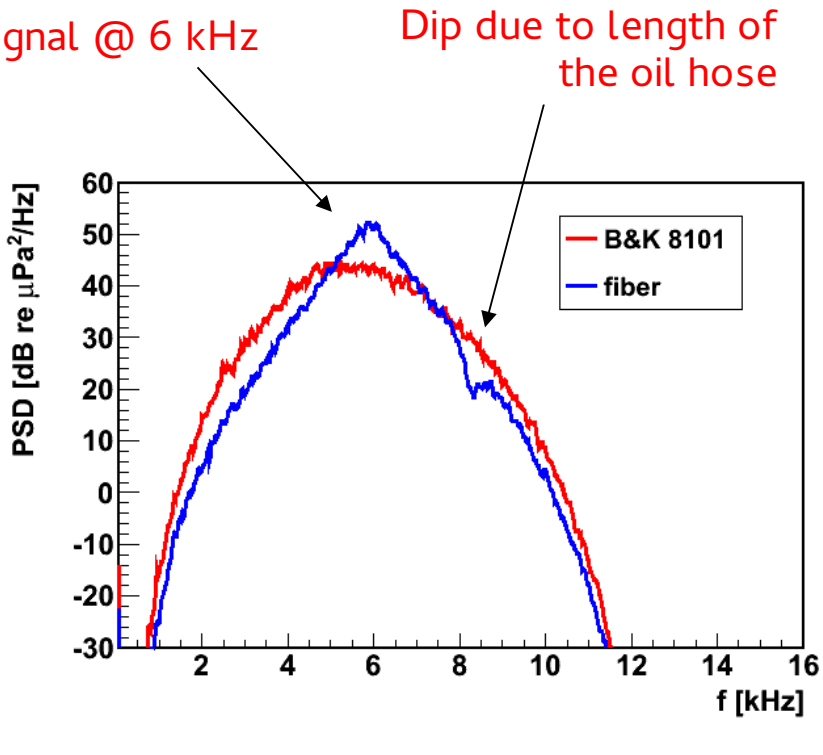
Reference hydrophone



Pulse reconstruction

- Pulse (also from echo) stands well above the noise.
- A power spectral density has been reconstructed from 100 pulses.
- Reconstructed pulse is as low as 1 mPa, the shape shows ringing.



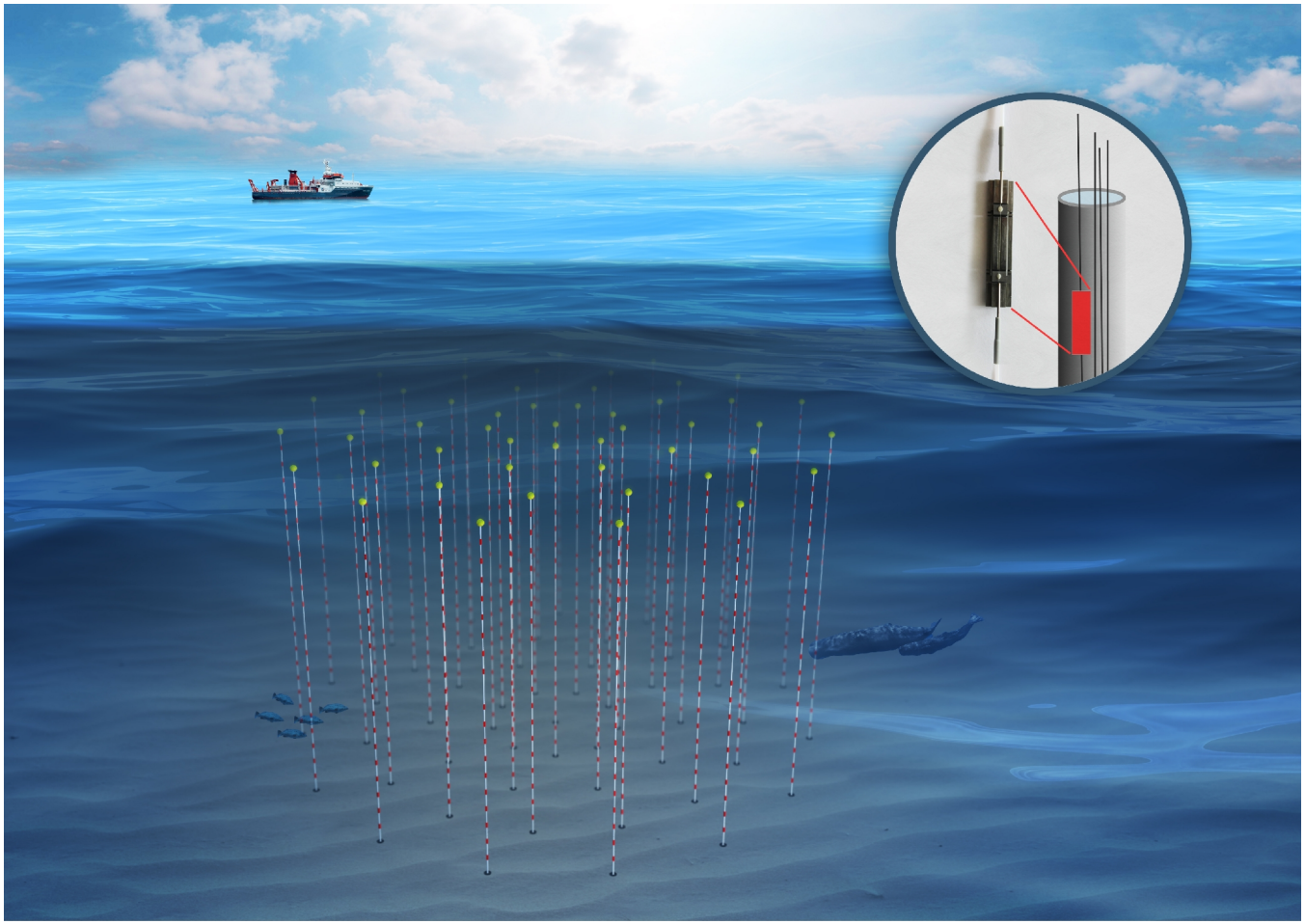


Conclusions

- Acoustic detection provides a way to study neutrino's with ultra high energy.
- Fiber laser hydrophones are sensitive enough to detect (cosmic-ray induced) pulses at the mPa level in the frequency range 5-20 kHz. Acoustic measurement of cosmic rays can become ocean noise limited.
- Only small difference in performance when hydrophone is used in oil hose.
- Impulse events show ringing. To be investigated further (important for marine biology).

- Implementation of fiber laser hydrophones have many advantages over piezo-hydrophones:
  - Sensitive, cheap and simple
  - No electronics X-talk, low power dissipation
  - Relative cheap to deploy

Concept experimental setup



> 100 strings, > 1000 hydrophones